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COOPERATIVE AND NON-COOPERATIVE MANAGEMENT OF THE NORTHEAST ATLANTIC COD FISHERY

by

Trond Bjørndal
Marko Lindroos

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Trond Bjørndal

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Marko Lindroos

Abstract

The fishery for Northeast Atlantic cod (*Gadus morhua*) in the Barents Sea is one of the most valuable fisheries in the North Atlantic. After the introduction of Extended Fisheries Jurisdiction, cod is a shared stock between Norway and Russia. Overfishing of quotas has been a concern for a number of years. The purpose of this article is to analyse cooperative and non-cooperative management of the Northeast Atlantic cod fishery. This will be done in a game theoretic context, based on different assumptions regarding important variables such as cost of effort and initial stock size. The game theoretic analysis will be based on an empirical bioeconomic model developed and estimated by Hannesson (2007, 2010). The case of cooperative management is analysed for different cost parameters and starting values of the stock. An interesting result is that the optimal policy gives rise to pulse fishing. As this involves effort (and harvests) varying from year to year, potentially imposing substantial social costs on the industry in years when the fishery is closed, a policy of constant effort is also considered. Finally, non-cooperative management is analysed.

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1. Introduction

The fishery for Northeast Atlantic cod (*Gadus morhua*) in the Barents Sea is one of the major and most valuable fisheries in the North Atlantic[1]. In some years, annual landings have exceeded one million tonnes; since 2004, they have varied between 490,000 – 640,000 tonnes.

After the introduction of Extended Fisheries Jurisdiction, cod is a shared stock between Norway and Russia. The two countries jointly set the Total Allowable Catch (TAC) which is split 50-50, with a given percentage being allocated to third countries. Overfishing of quotas has been a concern for a number of years.

The purpose of this article is to analyse cooperative and non-cooperative management of the Northeast Atlantic cod fishery. This will be done in a game theoretic context, based on different assumptions regarding important variables such as cost of effort and initial stock size. The game theoretic analysis will be based on an empirical bioeconomic model developed and estimated by Hannesson (2007, 2010).

The paper is organised as follows. The next section gives an overview over stock and catch development over time, while the management of the stock is reviewed in section 3. Bioeconomic modelling is undertaken in section 4, while alternative management regimes are considered in section 5. The results are discussed in the final section. Background biological data are given in the Appendix.

2. Stock development

The Northeast Atlantic cod (*Gadus morhua*) has its main spawning grounds on the coastal banks of Norway between 62º and 70º N and return to the Barents Sea after spawning. Cod, capelin, and herring are considered key fish species in the ecosystem and interactions among them generate changes which also affect other

[1] An important source on this fishery is given by: International Arctic Science Committee (Content Partner); Sidney Draggan (Topic Editor). 2008. "Fisheries and aquaculture in the Northeast Atlantic (Barents and Norwegian Seas)." In: Encyclopedia of Earth. Eds. Cutler J. Cleveland (Washington, D.C.: Environmental Information Coalition, National Council for Science and the Environment). [First published in the Encyclopedia of Earth March 29, 2007; Last revised August 29, 2008; Retrieved March 9, 2009].
http://www.eoearth.org/article/Fisheries_and_aquaculture_in_the_Northeast_Atlantic_(Barents_and_Norwegian_Seas)

fish stocks as well as marine mammals and birds (Bogstad *et al.*, 1997). Recruitment of cod and herring is enhanced by inflows of Atlantic water carrying large amounts of suitable food for larvae and fry of these species. Consequently, survival increases, so that juvenile cod and herring become abundant in the area. However, since young and juvenile herring prey on capelin larvae in addition to zooplankton, capelin recruitment might be negatively affected and thus cause a temporal decline in the capelin stock, an occurrence that would affect most species in the area since capelin is their main forage fish. Predators would then prey on other small fish and shrimps. In particular, cod cannibalism may increase and thus affect future recruitment of cod to the fishery (Hamre, 2003).

Management advice has been provided by the International Council for the Exploration of the Sea (ICES) from the early 1960s. A variety of conservation measures were recommended in order to increase yield per recruit and to limit the overall fishing mortality. The first TAC for cod was set in 1975, but was far too high. Although minimum mesh size regulations had been in force for some years at that time, it is fair to conclude that no effective management measures were in operation for demersal fish in the area prior to the establishment of the 200 mile Exclusive Economic Zones (EEZs) in 1977.

The Northeast Arctic cod stock has been jointly managed by Norway and Russia (earlier the Soviet Union) since 1977, when the 200-mile Exclusive Economic Zone was established. The primary control instrument is an upper limit on the total catch each year, but other controls such as a minimum mesh size and measures which aim at increasing the yield of the stock are also in place. The total catch quota is shared evenly by Russia and Norway, after setting aside about 15 percent of the total for third countries that have traditionally fished this stock. Most of the quotas given to each country fishing this stock are allocated between boats from the country in question. Norway and Russia monitor the fishing in their respective zones and take measures as they deem required against boats breaking the regulations.

Figure 1 gives annual data[2] on spawning stock size, landings and recruitment to the spawning stock for the period 1946-2007. Right after the Second World War, the stock was at a high level – almost 4.2 mill tonnes in 1946. Although there were substantial fluctuations over time, the trend in stock size was declining until 1980, when it levelled off around 900,000 tonnes for about a decade. Stock size increased in the 1990s to a peak of almost 2.4 mill tonnes in 1993, before falling again. Stock size in 2007 was recorded at 1.7 mill tonnes.

Landings have fluctuated substantially over time. In the period 1946-54, annual harvest averaged around 800,000 tonnes, increasing to more than 1.3 mill tonnes in 1956, the highest level ever recorded. Landings in excess of 1 million tonnes were also achieved in 1968-69 and 1974, however, this level does not appear to be sustainable, as landings were reduced below 300,000 tonnes in 1983-84. Since 2002, annual landings have varied between 490,000 – 640,000 tonnes.

Recruitment to the stock is highly variable, varying between a low of 37,000 tonnes in 1980 and 700,000 tonnes in 1966.

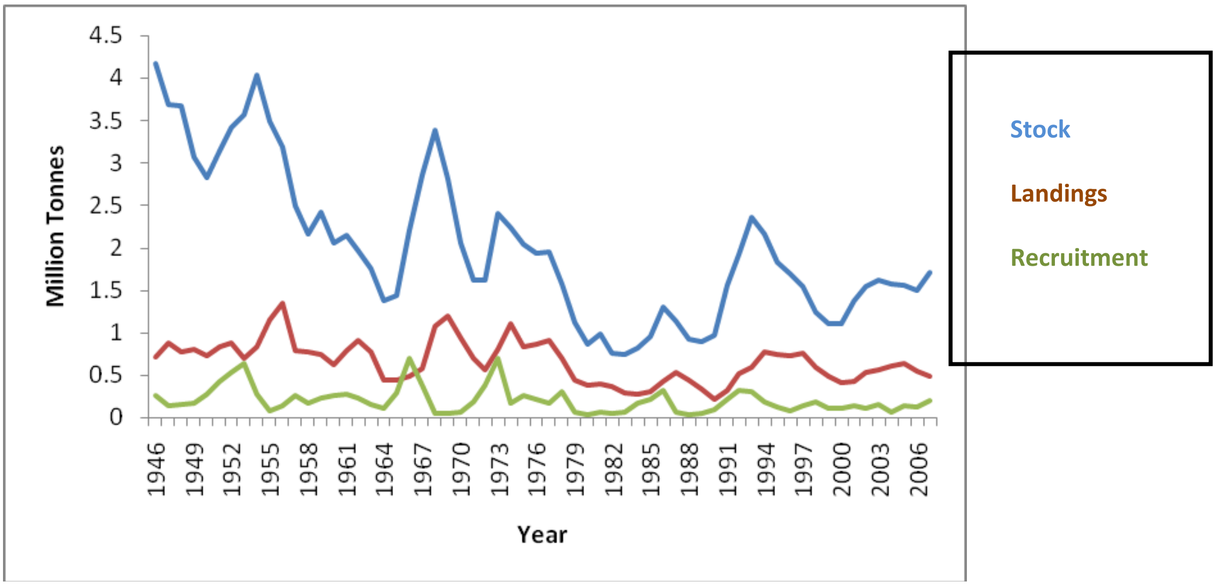

Figure 1. Stock Size, Landings and Recruitment per Year, 1946-2007. Mill. Tonnes.
Source: Appendix, Table A1.

[2] Spawning stock is defined as yearclasses three and older. Landings refer to catches of cod from yearclasses three and older, while recruitment is to the spawning stock.

Catches of Northeast Atlantic cod, 1995-2006, by country is given in the Appendix (Table A2). Although Norway and Russia take the largest catches, the fishery is also significant for fishermen from EU countries, especially Spain and United Kingdom. Most of the catch is caught by bottom trawl. The Norwegian quota is caught by vessels using passive fishing gear as well as more active gears such as bottom trawl.

3. Management

A series of agreements has been negotiated among the countries in the Northeast Atlantic that establish bilateral and multilateral arrangements for cooperation on fisheries management. The most extensive management regime in the Northeast Atlantic is that between Norway and Russia. A joint fisheries commission meets annually to agree on TACs. As noted above, the total quotas set are shared between the two countries – the allocation key is 50-50 for cod. A fixed additional quantity is awarded to third countries. The EU is given a major share of the third country quota of cod in the Norwegian waters north of 62º N as witnessed by the catch figures presented in the Appendix, Table A2. Spanish cod trawlers, along with fishing vessels from other EU member countries, fish for cod in the area of Svalbard Islands and Norwegian waters north of 62º north. This activity is conducted under International Agreements (Paris Treaty, EU-Norway Bilateral Agreement), regulating catches as well as conservation measures (TAC system).

An important aspect of the cooperation with Russia is that a substantial part of the Russian harvest in the Barents Sea is taken in the Norwegian zone and landed in Norway. In addition, there is exchange of quotas (Hoel, 1994). The cooperation also entails joint efforts in fisheries research and in enforcement of fisheries regulations.

The cooperation on resource management between Norway and Russia may generally be characterised as well functioning (Hønneland, 1993). However, agreed TACs by Norway and Russia have, in some years, exceeded those recommended by fisheries scientists. In addition, the actual catches have sometimes been larger than those agreed. Since the late 1990s, a precautionary approach has been gradually implemented in the management of the most important fisheries. However, retrospective analyses have shown that ICES estimates of stock sizes have often been too high, thereby incorrectly estimating the effect of a proposed regulatory measure on the stock. This has had the unfortunate effect that stock sizes for a given year are adjusted downward in subsequent assessments, rendering adopted management strategies ineffective (Korsbrekke *et al.*, 2001; Nakken, 1998). However, the Joint Norwegian–Russian Fisheries Commission has decided that from 2004 onwards multi-annual quotas based on a precautionary approach will be applied. A new management strategy adopted in 2003 shall ensure that TACs for any three-year period shall be in line with the precautionary reference values provided by ICES.

The two main elements of the Norwegian fisheries management system are restricting access through licensing schemes and restricting the harvesting through quotas (Årland and Bjørndal, 2002). There are also regulations of minimum mesh size, fish size etc. Capacity is restricted through licensing schemes in the trawler fleet. Some segments of the coastal fleet are subject to licensing; others to open access. A license is issued to a particular owner and a particular vessel and is not transferable. If a vessel is sold or replaced by a new one, a transfer of fishing license must be approved. Most vessels hold more than one license.

The quota restrictions are as follows. First, a Total Allowable Catch (TAC) is fixed, based on advice from ICES (most stocks are shared stocks). Second, the Norwegian quotas are then distributed among the main segments of the fishing fleet as group quotas*.* The trawler fleet are allocated Individual Vessel Quotas (IVQs) for the Northeast Atlantic cod. The IVQs vary from year to year and can be harvested freely during the year. Conventional (gear) offshore vessels are allocated IVQs too. Maximum quotas, giving maximum catch per vessel, dominate for the coastal fleet. The coastal fleet is often what is called "overregulated". This means that the sum of the vessels' maximum quotas exceeds the group quota allocated to the coastal vessels.

The total TAC for cod has not always been effectively implemented. Norway exceeded its allocated quota for a number of years after the joint Soviet–Norwegian control was put in place, because the agreement permitted Norwegian boats other than trawlers to continue fishing even if the Norwegian allocation had been taken. This problem has been minor or non-existing since the late 1980s. Unauthorised boats, mainly Icelandic, have also at times fished in an area called the Loophole outside the Norwegian and Russian EEZs, but this problem has also largely disappeared since an agreement with Iceland was reached in 1999.

Until recently, Norwegian investigations have indicated that Russia has exceeded its quota by perhaps as much as 100,000 tonnes per year, for an unknown number of years. The problem appears to be lax control of Russian trawlers fishing in the Russian zone. Monitoring catches has been made difficult *inter alia* by transfers of fish at sea (Hannesson, 2007). The situation may, however, be improving. According to industry sources, there was a substantial reduction in illegal landings from 2007 to 2008. Moreover, national quotas were not exceeded in 2009[3]. Whether this improvement in circumstances will continue, remains to be seen.

4. Bioeconomic Modelling

We will base the analysis on the empirical bioeconomic model developed by Hannesson (2007, 2010). We specify the following harvest function:

$$H_t = qE_tX_t \qquad (1)$$

where H_t is harvest, E_t is effort and X_t is stock size in year t, while q is the catchability coefficient. Net revenue from the fishery in year t, π_t, is given by

$$\pi_t = pH_t - cE_t \qquad (2)$$

where p is price and c is the constant unit cost of effort.

In bionomic equilibrium (Bjørndal and Munro, 1998), stock size is given by

$X_\infty = c/(pq)$.

Following Hannesson (2010), parameters are normalised so that p = q = 1, implying that

$X_\infty = c$,

where c is bionomic equilibrium or the break even stock level. In other words, it is not profitable to reduce the stock below c. Consequently,

[3] See: http://www.ices.dk/committe/acom/comwork/report/2010/2010/cod-arct.pdf.

$H_t = E_t X_t$ (2),

so that E_t represents the proportion of the stock harvested. Accordingly, E_t must lie between zero and one.

Hannesson (2010) provides the following point estimate:

c = 2,500.

This means that the stock will never be reduced below 2,500, which corresponds to a stock size of 2.5 million tonnes.

The fact that the cod stock consists of many year classes of fish implies that the development of the stock from one year to the next is largely determined by its size and the amount of fish caught. Hannesson (2010) considered the following specification:

$X_{t+1} – R_{t+1} = a(X_t - H_t) – b(X_t - H_t)^2$, (3)

where R_t is the recruitment of a new year class of fish in year t, and H_t is the landings of fish in year t.

Hannesson (2010) estimated the model for data for 1946–2005 and obtained the following parameter estimates:

a = 1.558

b = 0.000145.

Hannesson (2010) found only a weak relationship between spawning stock size and recruitment. He did, however, find strong serial correlation in recruitment, and estimated the following function:

$R_t = a_0 + a_1 R_{t-1} + a_2 R_{t-2} + a_3 R_{t-2}$

The following point estimates were obtained: a_0=144.4; a_1=0.616; a_2=-0.2279; a_3=-0.0863.

This empirical model will be employed in the analysis to follow.

5. Analysis of Alternative Management Regimes

In this section, we will analyse cooperative and non-cooperative management regimes. This will be done based on different conditions. We start by specifying these.

As described above, the Northeast Atlantic cod is shared between Norway and Russia, with a small quantity going to third countries. We will here assume there are two players in the fishery, Norway and Russia. We specify the following initial values for X_1 and R_1, which represent initial stock size and initial recruitment, respectively:

X_1 = 1.7 million tonnes or

X_1 = 3.3 million tonnes.

R_1 = 203.699 million tonnes

The 2007 stock size is estimated at 1.7 million tonnes (Table A1). As this is a somewhat low level, we will see what difference, if any, it would be to start out at a higher stock level, which is here set at 3.3 million tonnes. R_1 is set at the 2007 value, the most recent estimate available (Appendix, Table A1).

Under natural conditions, i.e., with no fishing, stock size will approach the carrying capacity of the environment. This is estimated at 4.189 million tonnes, more than double the current level. It is interesting to note that this is close to estimated stock size for 1946, the highest level observed in the data series (Appendix, Table A1).

We will first consider cooperative management.

5.1 Cooperative Management

Optimal Effort

We start out by analysing optimal effort. Assuming identical prices and costs for the two players, cooperative management essentially implies sole owner optimisation. This involves maximising the present value of eq. (2)

$$\text{Max} \sum_{t=1}^{T} \frac{(\mathrm{ph}_t - \mathrm{cE}_t)}{(1+r)^{t-1}}$$

subject to stock dynamics represented by eq. (3). Effort is allowed to vary from year to year, as part of an optimal policy. The analysis will be based on a simulation model, with T = 20 years the length of the simulation period. The discount rate is set at 10%.

We computed the dynamic optimum using the fmincon algorithm in Matlab. To reach the global optimum, the dynamic optimum was solved 1,000 times, starting from random initial guesses of the solution.

For each starting value for stock size, two cases are considered, representing different cost parameters – one high cost of 2,500 and one low cost of 1,400. In each case costs are the same for both players. Results for the four cases – Cooperative Management (CM) 1-4 - are presented in Table 1.

Assuming the 2007 level as the starting value for the stock, the high cost case is seen to give rise to a Net Present Value (NPV) of 1,725 million NOK, while the low cost case gives a NPV of 3,368 million NOK. A higher starting value for the stock will give rise to a higher NPV. As expected, cost per unit effort is a substantial determinant of NPV.

Table 1. Cooperative Management: Solutions for Optimal Effort.

Case	Starting value stock size (million tonnes)	Cost parameters	NPV (million NOK)
CM1	1.7	$c_1 = c_2 = 2,500$	1,725
CM2	1.7	$c_1 = c_2 = 1,400$	3,368
CM3	3.3	$c_1 = c_2 = 2,500$	2,228
CM4	3.3	$c_1 = c_2 = 1,400$	4,312

Figures 1 – 3 illustrate results for important variables for case CM1, showing optimal effort, harvest and stock size, respectively, over the 20 year period. The most striking result is that an optimal policy calls for pulse fishing, with harvesting in years 4, 9, 14, 18 and 20, i.e., the stock is harvested in five out of 20 years, being closed in other years. When the fishery is open, effort is about 0.8, except for year 18, when it is 0.15. This result is due to the transient phase and should not be considered in the long run optimal management.

The pulse fishing result is due to serial correlation in the growth function, with recruitment in one period depending on recruitment in previous years. This is the most important modification of our model compared to a standard bioeconomic model. In models that explicitly specify the age-structure of the population, pulse fishing is a common result.

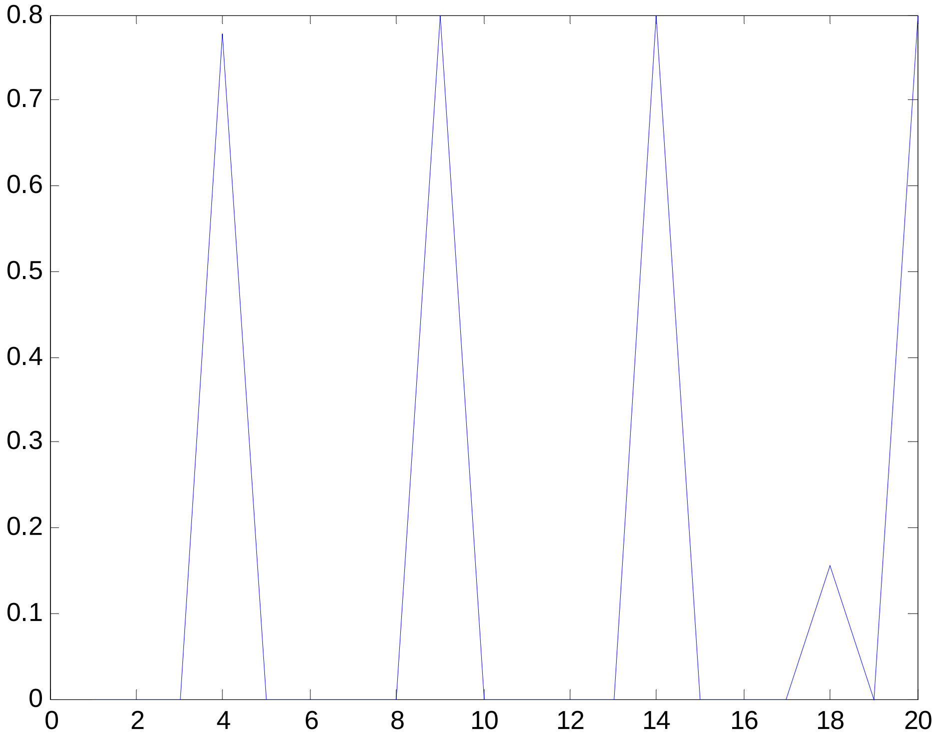

Figure 1. Optimal Effort as Fraction of the Stock Years 1-20. Case CM1.

As shown in figure 3, initial stock size is 1.7 million tonnes. Stock size is then allowed to increase. Pulse fishing occurs for the first time in year four with a harvest of about 3 million tonnes. Harvest quantify is seen to be 3 – 3.5 mill tonnes in years 4, 9, 14 and 20; 0.5 mill tonnes in year 18, otherwise zero. Stock size varies between 1.5 – 4.2 mill tonnes.

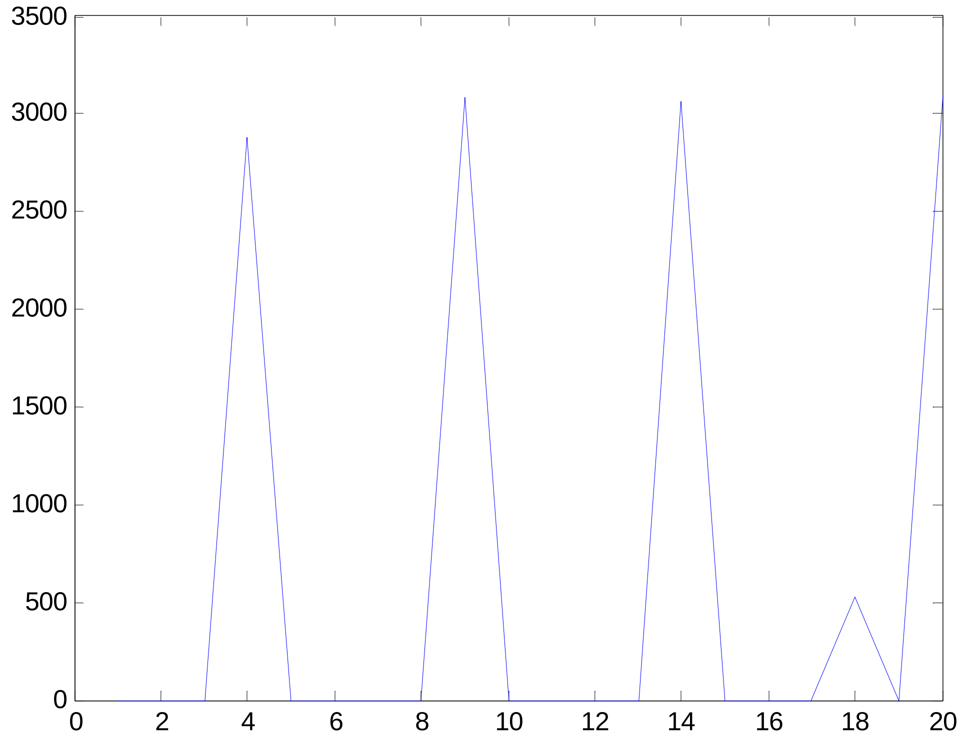

Figure 2. Optimal Catch Year 1-20. Case CM1. ‘000 Tonnes.

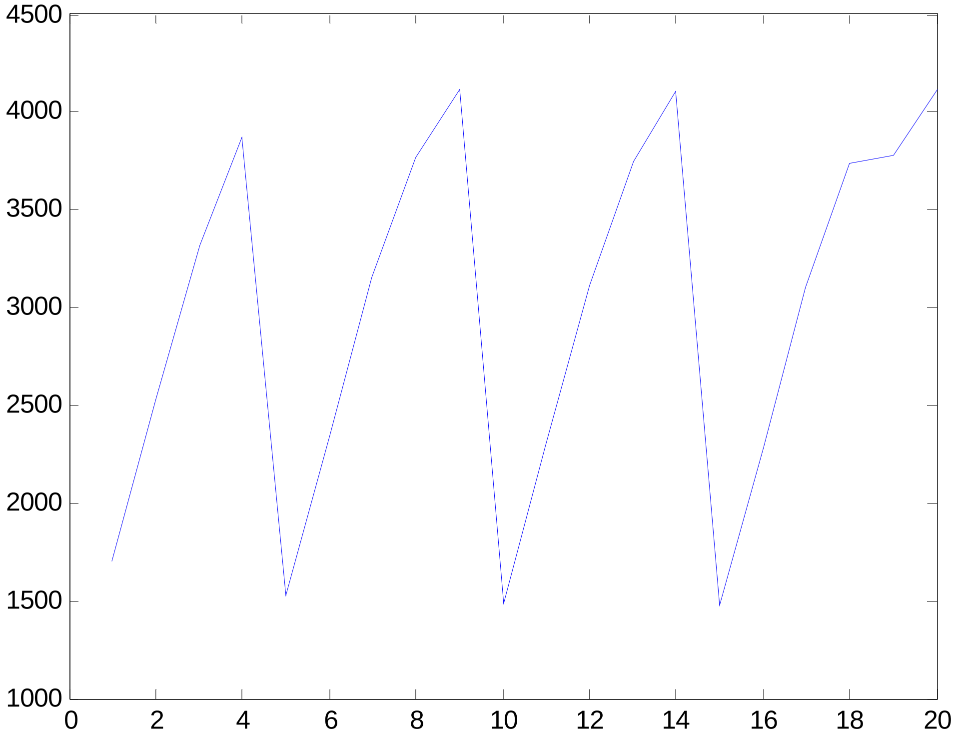

Figure 3. Stock Size Years 1-20. Case CM1. '000 Tonnes.

Figures 4-6 illustrate the low cost case (CM2). This case also give rise to pulse fishing, however, as can be seen in Figures 4 and 5, fishing occurs at more frequent intervals than in the high cost case, with fishing taking place in seven out of 20 years. This makes intuitive sense, as fishing is more profitable in the low cost case than in the high cost one.

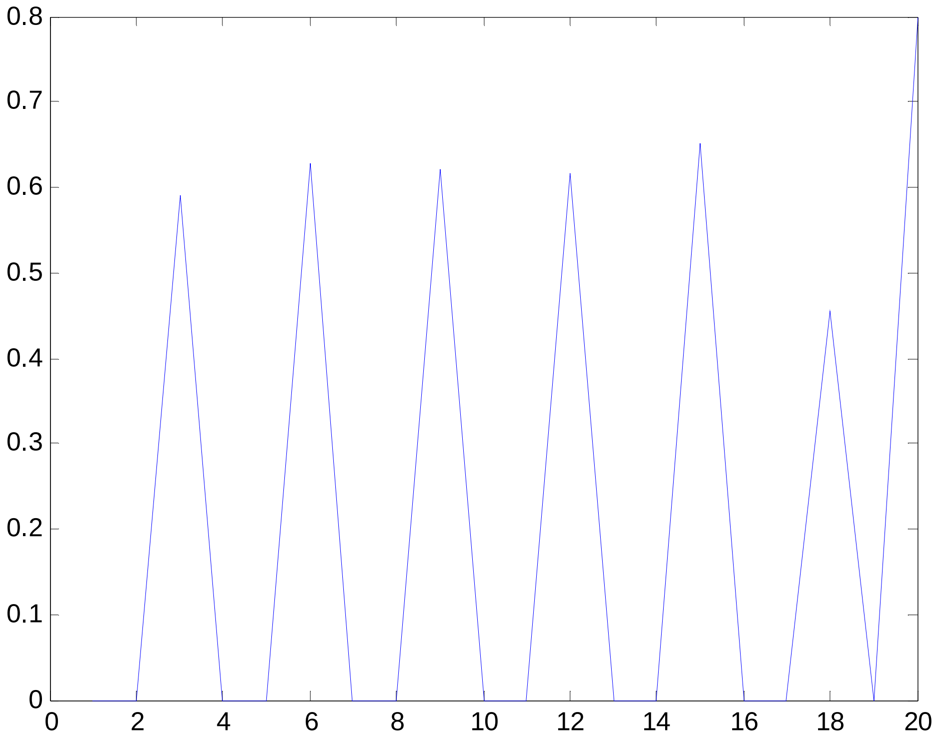

Figure 4. Fishing Effort per Year. Case CM2.

It is interesting to compare stock development in the two cases. In the high cost case, stock size varies between a low of about 1.5 million tonnes and a high of about 4 million tonnes (Figure 3). In the low cost case, stock varies between about 2 million tonnes and 3.2 – 3.4 million tonnes (Figure 6). The reason for this difference is that in the high cost case, a large increase in stock size is required in order to reduce unit cost of harvesting.

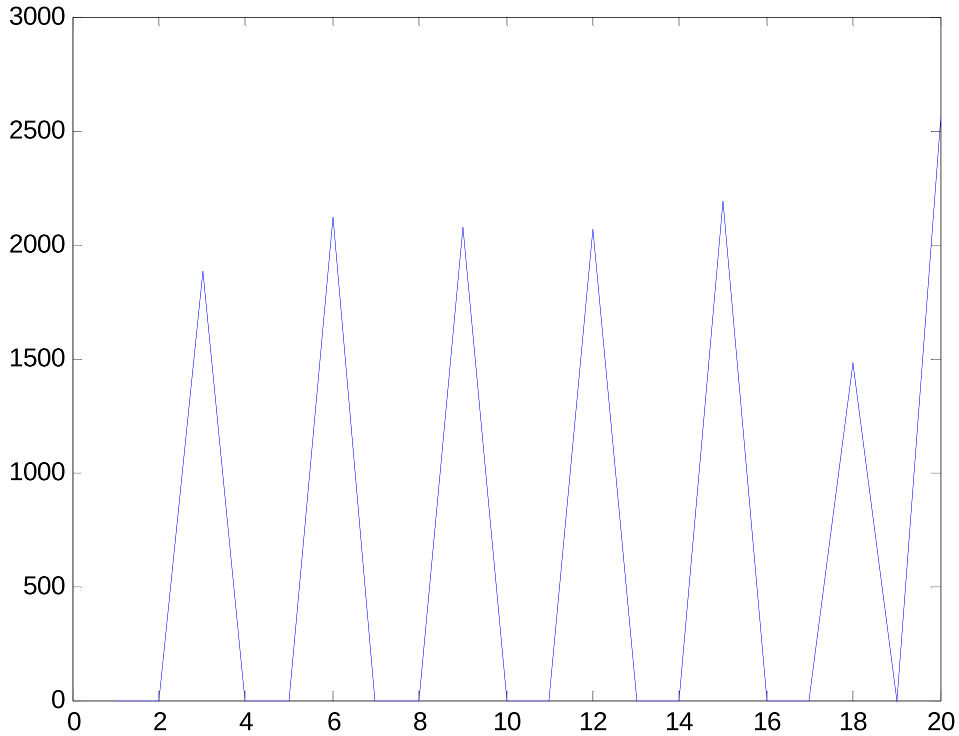

Figure 5. Harvest Quantity per Year. Case CM2.

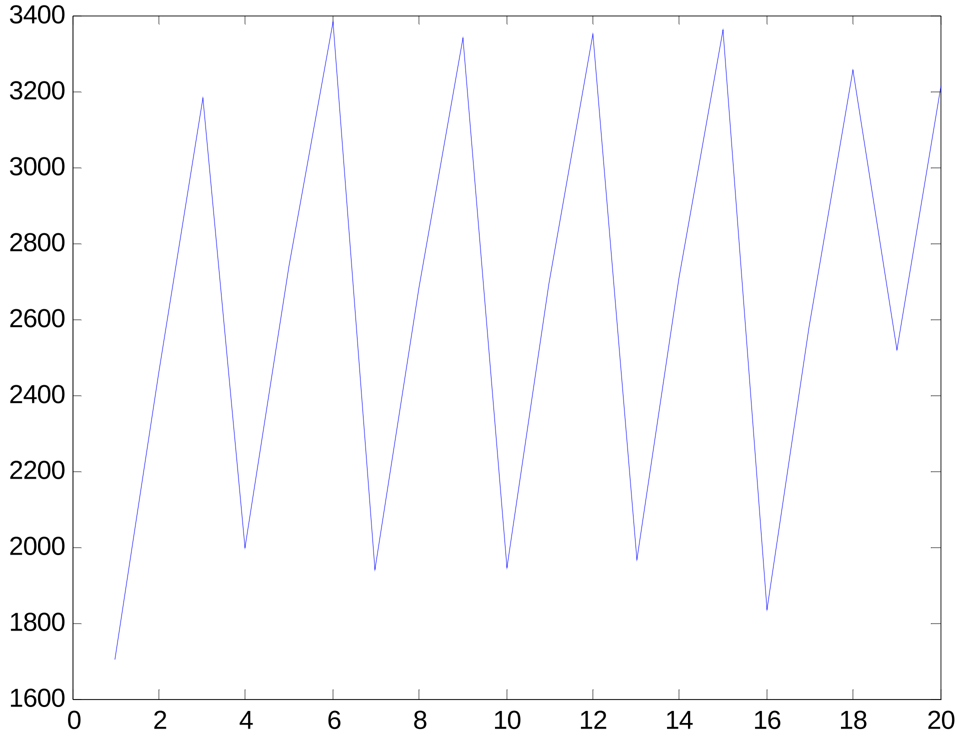

Figure 6. Stock Size per Year. Case CM2. '000 Tonnes.

Bjørndal and Brasao (2006), in an analysis of the Northeast Atlantic and Mediterranean bluefin tuna fishery, also found pulse fishing to be optimal. In their case, five different gear types, with different levels of profitability, were considered. The "pulses" were found to be of different length for the different gear types, with the most profitable gear type being inactive for a shorter period of time than the least profitable gear type. This provides an analogy to the high and low cost cases considered for cod.

Constant Effort

In the cases considered hitherto, effort is seen to vary substantially from year to year, from zero to very high levels. This is not realistic because a policy of this nature might impose substantial social costs in years when the fishery is closed. There are also costs to fishing firms that are ignored by only considering variable costs. Most relevant in this regard is adjustment costs between active and inactive years, when vessel and equipment must be laid up and labour must be fired and hired – since this is by far their most important fishery. From a market and marketing perspective, such a policy would also not be desirable.

We now assume that effort is constant from year to year, a policy that is sometimes recommended in fisheries management. This implies that a constant fraction of the stock is harvested every year. Once more, a high cost and a low cost case are evaluated with results presented in Table 2, denoted CM 5-8.

In the high cost case, effort is maintained at a level of 0.14 every year, while in the low cost case it is 0.22. Effort is divided evenly between the two players. Actual harvest will vary over time with changes in stock size.

For a starting value of 1.7 million tonnes for the stock, the high cost case gives rise to an NPV of 816 million NOK, less than half the NPV for the optimal case. The low cost case gives a NPV of 2,688 million NOK, compared to 3,368 million NOK (Table 1). Thus, constant effort is seen to imply a loss in net present value. Moreover, the loss is greater for the high cost case than for the low cost case.

Table 2. Cooperative Management: Solutions for Constant Effort.

Case	Starting value stock size (million tonnes)	Cost parameters	Optimal effort (E)	NPV (million NOK)	Steady state stock size ('000 tonnes)
CM5	1.7	$c_1 = c_2 =$ 2,500	0.14	816	3,692
CM6	1.7	$c_1 = c_2 =$ 1,400	0.22	2,688	3,177
CM7	3.3	$c_1 = c_2 =$ 2,500	0.18	1,569	3,460
CM8	3.3	$c_1 = c_2 =$ 1,400	0.26	3,848	2,843

The high cost and the low cost cases correspond to steady state stock sizes of 3,692,000 and 3,177,000 tonnes, respectively. As the carrying capacity of the environment was found to be close to 4.2 million tonnes, the high cost case involves a low degree of exploitation of the stock.

A higher starting value for the stock (cases CM7 and CM8) give rise to higher NPVs and steady state stock levels than the comparable cases with lower initial stock value.

Figures 7 and 8 illustrate catch and stock development, respectively, for the high cost case (CM5). Stock size starts out at 1.7 million tonnes and reaches the steady state after about 10 years with a concomitant increase in harvest.

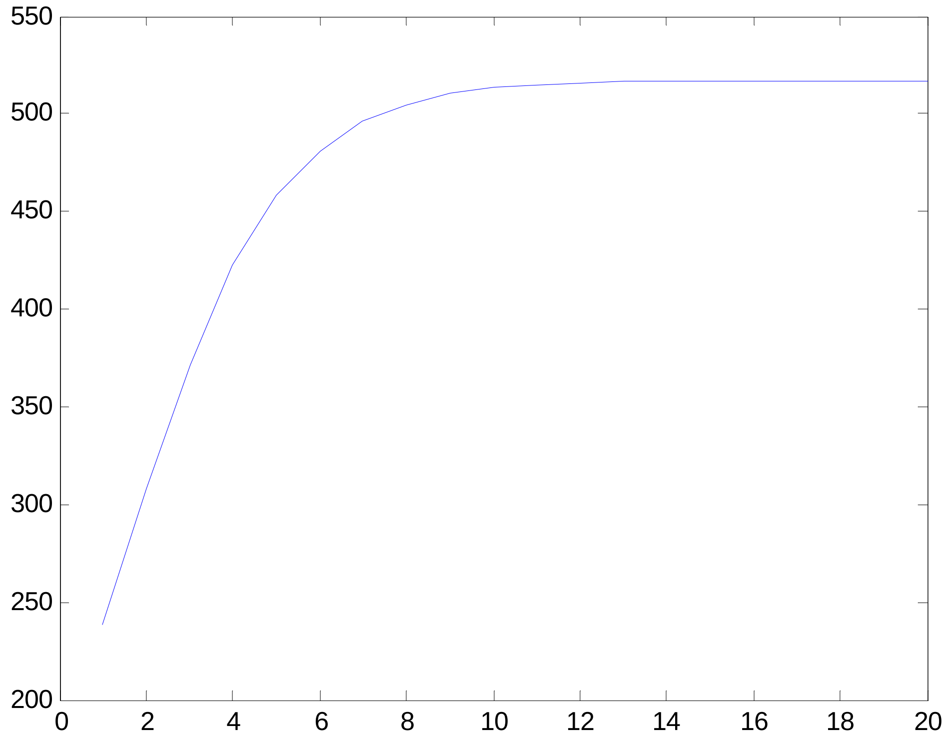

Figure 7. Catch per Year for Case CM5 (Constant E = 0.14). '000 Tonnes.

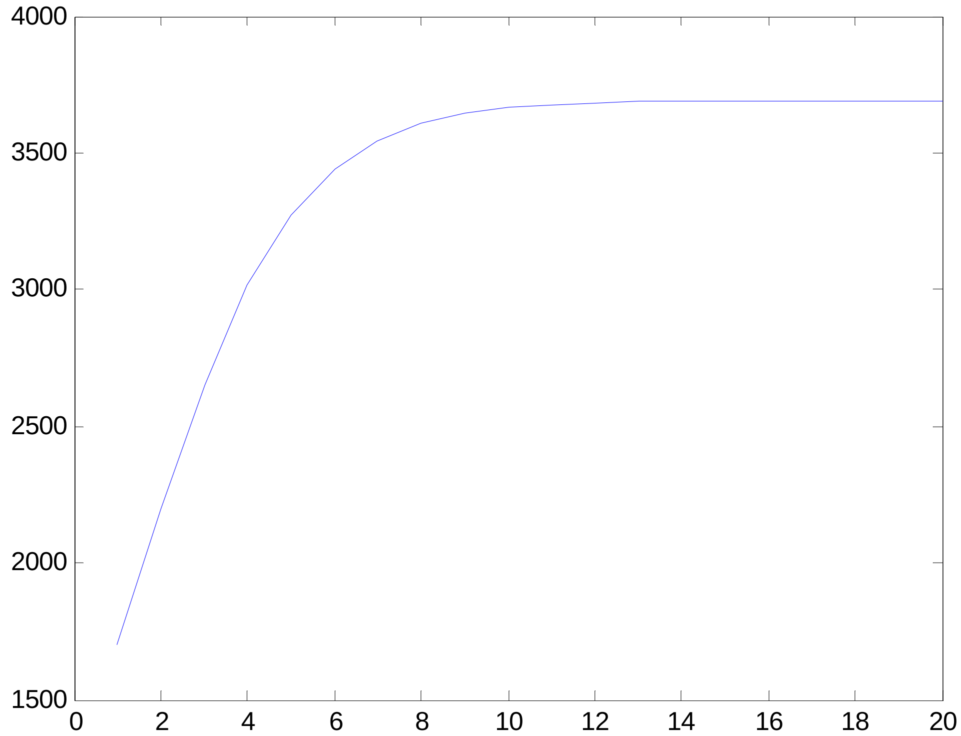

Figure 8. Development in Stock Size over Time for Case CM5. (E = 0.14). '000 Tonnes.

5.2 Non-Cooperative Game

Next, we will consider non-cooperative games. This will be done for three alternatives with regard to cost parameters:

1) High costs: $c_1 = c_2 = 2{,}500$

2) Player 2 has cost advantage: $c_1 = 2{,}500$; $c_2 = 1{,}400$

3) Low costs: $c_1 = c_2 = 1{,}400$

Cases 1) and 2) correspond to the high and low cost cases previously considered. In case 2), however, player 2 has a cost advantage, having lower costs of effort then player 1. As before, we will do the analysis for two starting values of the stock.

The game is solved as a one-shot game where in the beginning of the game countries choose their fishing efforts that are employed for the rest of the game. The Nash equilibrium is solved iteratively by letting each country in its turn maximise its NPV for a given effort of the other player. The equilibrium is found when optimal effort remains unchanged for the players.

The results are summarised in Table 3, for two starting values of the stock, giving a total of six cases: NC1 - 6. For case NC1, where the players have equal costs, effort is 0.20, compared to 0.14 in the cooperative case, and stock size is reduced from 3.692 million tonnes to 3.325 million tonnes. NPV is reduced from 816 million NOK under cooperative management to 680 million NOK under non-cooperation.

Comparing the two low cost cases, NC3 and CM6, effort increases from 0.22 to 0.30, stock size decreases from 3.177 million tonnes to 2.456 million tonnes, and NPV from 2,688 million tonnes to 2,266 million tonnes.

Results for case NC2, where country 2 has a cost advantage, are interesting. Essentially this involves the fishery being dominated by country 2 with E2 = 0.21, with country 1 playing a minor part (E = 0.03) and almost all benefits accruing to country 2. Steady state stock size is 3.015 million tonnes, comparable to the result for cooperative management (case CM6). These results conform to the theoretical results derived by Clark (1980).

For the other cases considered, results are qualitatively similar to those discussed here. As cost decreases, effort increases and steady state stock size decreases. This is as expected.

Table 3. Comparison of Non-Cooperative Games. NPV in Million NOK. Stock Size in '000 Tonnes.

Case	Initial stock size (million tonnes)	c_1	c_2	Effort	NPV1	NPV2	NPV1 + NPV2	Stock Size
NC1	1.7	2,500	2,500	0.20	340	340	680	3.325
NC2	1.7	2,500	1,400	E1=0.03 E2=0.21	27	2.332	2,359	3.015
NC3	1.7	1,400	1,400	0.30	1,133	1.133	2,266	2.456
NC4	3.3	2,500	2,500	0.24	682	682	1,364	3,015
NC5	3.3	2,500	1,400	E1=0.07 E2=0.22	198	2,855	3,053	2,556
NC6	3.3	1,400	1,400	0.34	1,669	1,669	3,338	2,045

6. Summary and Discussion

The current analysis has given some very interesting results. Cooperative management of the resource is found to give rise to a very high net present value, although it depends on the cost parameters and the initial stock level.

A striking result from the analysis is that an optimal policy calls for pulse fishing. In the low cost case, fishing occurs at more frequent intervals than in the high cost case. This makes intuitive sense, as fishing is more profitable in the low cost case than in the high cost one.

The pulse fishing result is due to serial correlation in the growth function, with recruitment in one period depending on recruitment in previous years. In models that explicitly specify the age-structure of the population, pulse fishing is a common result.

An optimal policy involves effort varying from year to year. This is not realistic because a policy of this nature might impose substantial social costs when the fishery is closed. For this reason, a constant effort policy is also considered, i.e., a policy where a constant fraction of the stock is harvested every year.

Constant effort is seen to imply a loss in net present value. Moreover, the loss is greater for the high cost case than for the low cost case. This, however, disregards possible social costs implied by effort varying from year to year.

Non-cooperation is also analysed. The game is solved as a one-shot game where in the beginning of the game countries choose their fishing efforts that are employed for the rest of the game. Net present value is reduced compared to the case of cooperative management.

In one case considered, country 2 has a cost advantage. The outcome involves the fishery being dominated by country 2, with country 1 playing a minor part and almost all benefits accruing to country 2.

In addition, the analysis has allowed us to identify some interesting topics for future research. While constant and non-constant strategies were considered for the cooperative case, for non-cooperative games only constant strategies were analysed. In the continuation of this research, non-constant strategies will be considered.

As discussed in the background section, overfishing has been an important aspect of the Northeast Atlantic cod fishery for many years. Typically this is analysed through non-cooperative games. Nevertheless, the fishery is characterised by cooperative management. What then happens in the real world, is that one nation may break the cooperative agreement. Often, it takes time for the other agent to detect this and respond. In future research, we would like to include this kind of delayed response into non-cooperative games.

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APPENDIX: BIOLOGICAL DATA

Table A1. Annual Adult Stock Size, Landings and Recruitment 1946-2007. Tonnes.

	Stock	Landings	Recruitment
1946	4,168,882	706,000	254,849
1947	3,692,801	882,017	136,099
1948	3,665,819	774,295	150,481
1949	3,065,111	800,122	173,289
1950	2,830,103	731,982	274,914
1951	3,141,009	827,180	433,501
1952	3,407,679	876,795	524,969
1953	3,557,376	695,546	636,151
1954	4,039,204	826,021	282,297
1955	3,488,383	1,147,841	87,289
1956	3,189,831	1,343,068	145,069
1957	2,495,895	792,557	265,578
1958	2,164,149	769,313	168,920
1959	2,415,826	744,607	239,291
1960	2,050,805	622,042	268,482
1961	2,137,149	783,221	284,221
1962	1,957,006	909,266	233,068
1963	1,747,579	776,337	151,061
1964	1,374,529	437,695	111,764
1965	1,440,693	444,930	295,238
1966	2,198,418	483,711	696,327
1967	2,852,164	572,605	375,671
1968	3,387,455	1,074,084	54,435
1969	2,805,591	1,197,226	49,297
1970	2,057,698	933,246	72,929
1971	1,610,969	689,048	182,148
1972	1,621,485	565,254	385,821
1973	2,401,955	792,685	691,201
1974	2,236,387	1,102,433	167,653
1975	2,037,430	829,377	254,863
1976	1,931,396	867,463	214,880
1977	1,950,748	905,301	170,547
1978	1,576,565	698,715	312,860
1979	1,114,381	440,538	69,471
1980	863,862	380,434	37,188
1981	983,658	399,038	73,926
1982	750,871	363,730	56,177
1983	738,675	289,992	61,727
1984	817,596	277,651	167,089
1985	957,513	307,920	216,277
1986	1,294,448	430,113	323,074
1987	1,126,275	523,071	60,419
1988	915,458	434,939	43,385
1989	890,359	332,481	51,662

1990	962,672	212,000	96,614
1991	1,561,711	319,158	213,302
1992	1,912,190	513,234	317,280
1993	2,359,674	581,611	307,844
1994	2,155,298	771,086	190,449
1995	1,825,929	739,999	132,065
1996	1,686,862	732,228	85,405
1997	1,532,187	762,403	144,619
1998	1,230,183	592,624	183,376
1999	1,101,326	484,910	111,306
2000	1,101,505	414,868	117,611
2001	1,375,566	426,471	147,741
2002	1,542,075	535,045	110,714
2003	1,608,810	551,990	155,977
2004	1,565,794	606,445	74,315
2005	1,555,835	641,276	135,219
2006	1,496,200	537,642	128,094
2007	1,700,760	486,883	203,699

Source: http://www.ices.dk/workinggroups/ViewWorkingGroup.aspx?ID=28

Table A2. Northeast Atlantic cod. Nominal catch (t) by countries (ICES Sub-areas I and Divisions IIa and IIb combined.)

Year	Faroe Islands	France	Greenland	Germany	Norway	Spain	United Kingdom	Russia	Iceland	Others	Total
1995	22,262	4,912	7,462	7,428	319,987	15,505	16,329	296,158	34,214	15,742	739,999
1996	17,758	5,352	6,529	8,326	319,158	15,871	16,061	305,317	23,005	14,851	732,228
1997	20,076	5,353	6,426	6,680	357,825	17,130	18,066	313,344	4,200	13,303	762,403
1998	14,290	1,197	6,388	3,841	284,647	14,212	14,294	244,115	1,423	8,217	592,624
1999	13,700	2,137	4,093	3,019	223,390	8,994	11,315	210,379	1,985	5,898	484,910
2000	13,350	2,621	5,787	3,513	192,860	8,695	9,165	166,202	7,562	5,115	414,870
2001	12,500	2,681	5,727	4,524	188,431	9,196	8,698	183,572	5,917	5,225	426,471
2002	15,693	2,934	6,419	4,517	202,559	8,414	8,977	184,072	5,975	5,484	445,045
2003	19,427	2,921	7,026	4,732	191,977	7,924	8,711	182,160	5,963	6,149	436,990
2004	19,226	3,621	8,196	6,187	212,117	11,285	14,004	201,525	7,201	6,082	489,445
2005	16,273	3,491	8,135	5,848	207,825	9,349	10,744	200,077	5,874	7,660	475,276
2006[a]	16,480	3,834	8,164	3,769	201,185	9,219	10,594	203,775	5,915	6,261	469,197

[a]Provisional figures.
Source: ICES AFWG Report 2007.